VIRTUAL REALITY INTERFACES FOR SURFACE TELEROBOTICS FROM THE LUNAR GATEWAY.

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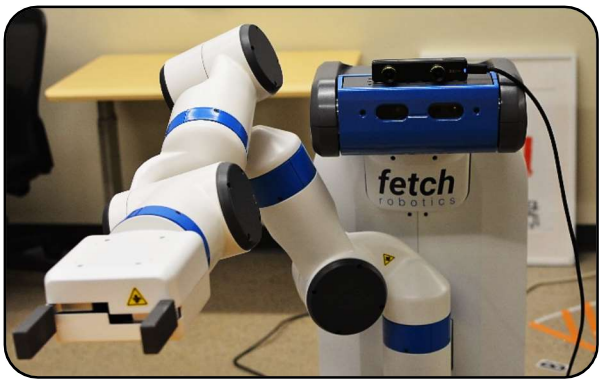

Figure 1: *A Fetch Mobile Manipulator robot with a 7-DOF arm utilized for simulating long-distance teleoperation assembly tasks.*

Introduction: There has been recent renewed interest in returning to the Moon and the development of a Lunar Gateway as part of a larger effort for sustainable deep space exploration. Surface telerobotic assembly and exploratory missions will be powerful enablers for researchers to learn more about the environment and establish a human presence on the lunar surface with minimal risk. To help inform future planetary surface telerobotic research and operations, our team has explored the utilization of novel interfaces that utilize virtual reality (VR) technology to leverage the increased bandwidth afforded by the Gateway outpost. We envision astronauts directly teleoperating surface robots through VR head-mounted displays (HMDs) from the Gateway.

VR HMD Teleoperation Interface: A stereo video pass-through camera is mounted to the head of a robot (Figure 1) that streams duel video feeds (one for each eye) to a remote user allowing the user to see from the robot's point-of-view. VR HMD interfaces inherently provide benefits absent in standard teleoperation interfaces, specifically that of depth perception through stereopsis and improved immersion.

VR HMD Preliminary Experiment: Our first experiment aimed at establishing a baseline of user performance improvements when completing various subtasks that one would see in a robot teleoperation assembly task when using a VR HMD interface compared to a traditional 2D monitor interface. We ran a 2x1 within-subjects experiment (N=12) with both interfaces using identical control inputs and found efficiency improvements of 33% in precision stacking subtasks (Figure 2) and 15% in sorting subtasks (Figure 3) when using the VR HMD interface. In addition, 92% of participants (all but one participant) rated the VR HMD condition as the subjectively preferred interface for assembly subtasks.

Figure 2: *Experiment Precision Stacking Task.*

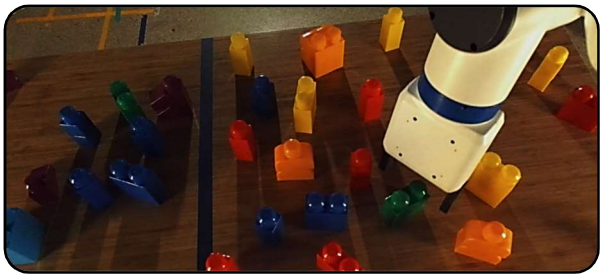

Figure 3: *Experiment Sorting Task.*

Complex VR HMD Interfaces Experiment: To fully examine the full capabilities that VR HMD technologies afford, a follow-up experiment examines the impact of more feature-rich VR HMD designs in various teleoperation tasks. Features include: integration of Lidar point clouds that allow the user to "step out" of the robot and physically explore a generated world mesh as well as "seeing-through" the robot when occluding the camera's view; head and hand motion controls for more natural and intuitive control of the robot; and augmented reality (AR) UI overlays that provide additional assistive data to the user (Figure 4).

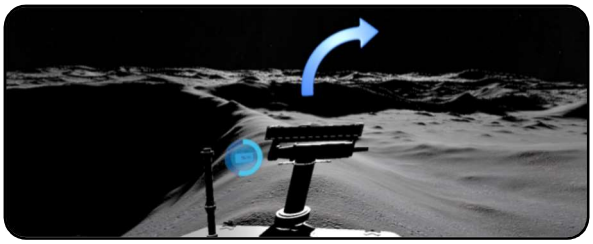

Figure 4*: Rendering of a prototype AR UI overlay.*

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